2015

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Christos Argyropoulos
University of Nebraska-Lincoln, christos.argyropoulos@unl.edu

Applied Computational Electromagnetics (ACES), 2015 31st International Review of Progress in
Publication Year: 2015 , Page(s): 1 - 2

Tunable Absorption Based on Plasmonic Nanostructures Loaded with Graphene

Christos Argyropoulos

Department of Electrical and Computer Engineering
University of Nebraska-Lincoln, Lincoln, Nebraska, 68588, USA
christos.argyropoulos@unl.edu

***Abstract* —** We present simulations of a hybrid graphene-plasmonic device constituted by periodic metallic nanowires placed over a dielectric spacer layer and a metallic film. The spacer layer is composed of a thin silica layer combined with an one-atom-thick graphene sheet. An electrically controlled ultra-compact absorption modulator can be realized based on the proposed theoretical device.

Index Terms – Absorber, graphene, grating, plasmonics.

I. INTRODUCTION

Research on plasmonic systems is currently shifting towards the incorporation of tunable, nonlinear, active and reconfigurable materials, which may lead to integrated nanophotonic devices with more pronounced and intriguing functionalities in terms of light manipulation and control [1].

In particular, the efficient concentration of light in subwavelength volumes and the resulting enhanced fields serve as an excellent platform to boost tunability and nonlinear optical processes [2-5]. One promising and practical choice among the plethora of recently introduced materials to achieve tunable plasmonic operation is graphene.

Plasmonic nanorod antennas [6] combined with graphene were employed to experimentally observe electrical tunability of the scattering and reflection response, respectively, at near-infrared (IR) frequencies. Electrolyte gating made by ionic liquid was used in both cases to control the plasmon or Fano resonance through efficiently varying the graphene's doping level.

Here, we will theoretically demonstrate an alternative and more practical hybrid graphene/plasmonic resonating system, where strong interaction between graphene and the impinging radiation is obtained, thus, allowing for tunable absorption performance at the technologically interesting telecommunication (near-IR) wavelengths. The proposed theoretical design may lead to electrically controlled ultra-compact efficient absorption modulators.

II. THEORY

The geometry of the proposed hybrid system is shown in Fig. 1. It is composed of an array of film-coupled shallow plasmonic nanowires. The metallic parts of the proposed device are made of silver (Ag), where the silver losses are taken into full account in our analysis and the silver permittivity is obtained from experimental data [7]. The infinitely long nanowire corrugations have a square cross-section shown in Fig. 1 with width $l = 100nm$. They are periodically arranged over the silver film with a periodicity equal to $w = 300nm$. The metallic film has thickness $h = 27nm$ and stands over a semi-infinite glass substrate (not shown in Fig. 1). Finally, the corners of the square rectangular corrugations nanowires are rounded to better comply with a potential experimental verification of the structure and rule out possible numerical artifacts.

The in-plane fridging electromagnetic fields are localized and enhanced with this configuration, interacting strongly with the graphene. Figure 1 also shows that a thin silica (SiO_2) spacer layer is placed between the nanowires and the silver substrate with an easily controllable thickness, which can be highly subwavelength. In the current study, the thickness of this layer is assumed to be $g = 3nm$. Graphene is placed over the thin silica spacer layer. The graphene's thickness is assumed to be $1nm$, in agreement with several previous studies of hybrid graphene/plasmonic devices, where full-wave simulations were used to verify the experimental results [6].

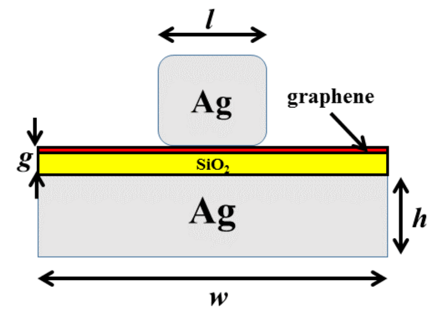

Fig. 1. The cross-section profile of the periodic film-coupled nanowires loaded with graphene.

III. NUMERICAL RESULTS

In order to demonstrate efficient tunability in the absorption spectrum obtained by this hybrid graphene/plasmonic system, we weakly vary the Fermi energy of graphene. Electrostatic gating of graphene based on ionic liquid electrodes is assumed [6]. The permittivity of graphene as a function of frequency and doping level is given in [6]. The results are reported in Fig. 2. Almost 20% decrease in the absorption resonant peak is obtained, when the Fermi energy is equal to $E_F = 0.5eV$. The decrease in the absorption in the presented hybrid system is due to the ultrastrong interaction between the impinging radiation and the in-plane properties of the graphene monolayer. Ultimately, it is just based on the altered properties of the doped graphene, which strongly interact with the fridging fields at the edges of the metallic corrugations.

IV. CONCLUSIONS

To conclude, we have presented simulations of a new hybrid graphene/plasmonic device, which can achieve tunable absorption in the technologically interesting telecom (near-IR) frequency range. Graphene was grown below the silver corrugations and is strongly coupled to the fridging fields of the proposed plasmonic system. The doping level in graphene has practical and relative low values. The proposed device provides an ideal platform to tame and control the absorption by purely metallic structures in a unique way. Several integrated nanophotonic components are envisioned based on the proposed device, such as ultrafast photodetectors with enhanced responsivity, new biosensors and efficient electro-optical modulators.

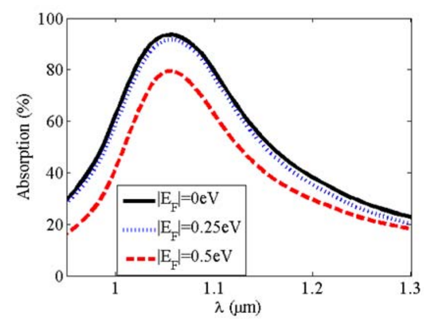

Fig. 2. Computed absorption versus incident radiation's wavelength of the proposed hybrid graphene/plasmonic structure. The absorption decreases, as we increase the Fermi energy from 0eV (undoped graphene) to 0.5eV (heavily doped graphene).

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